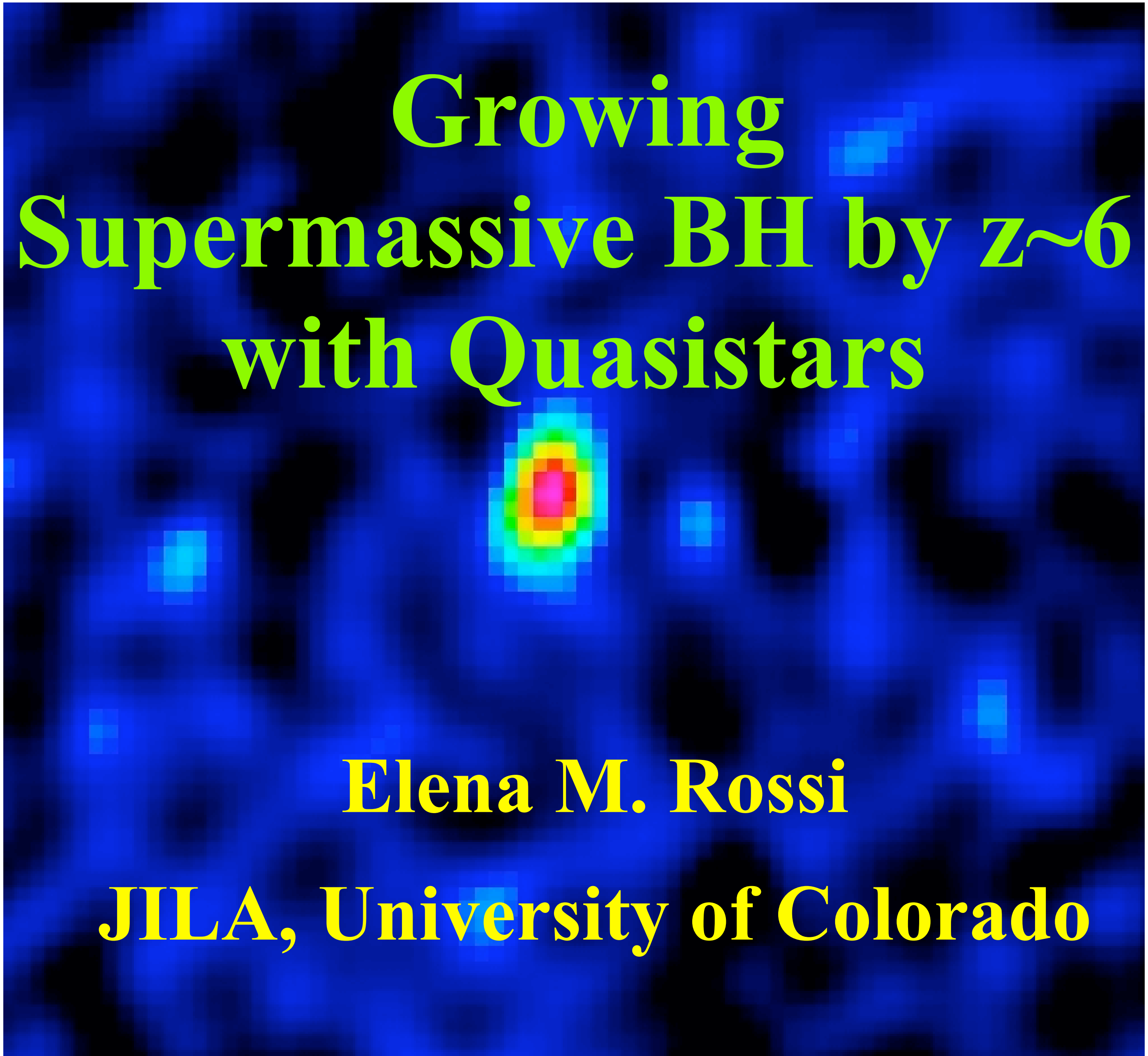
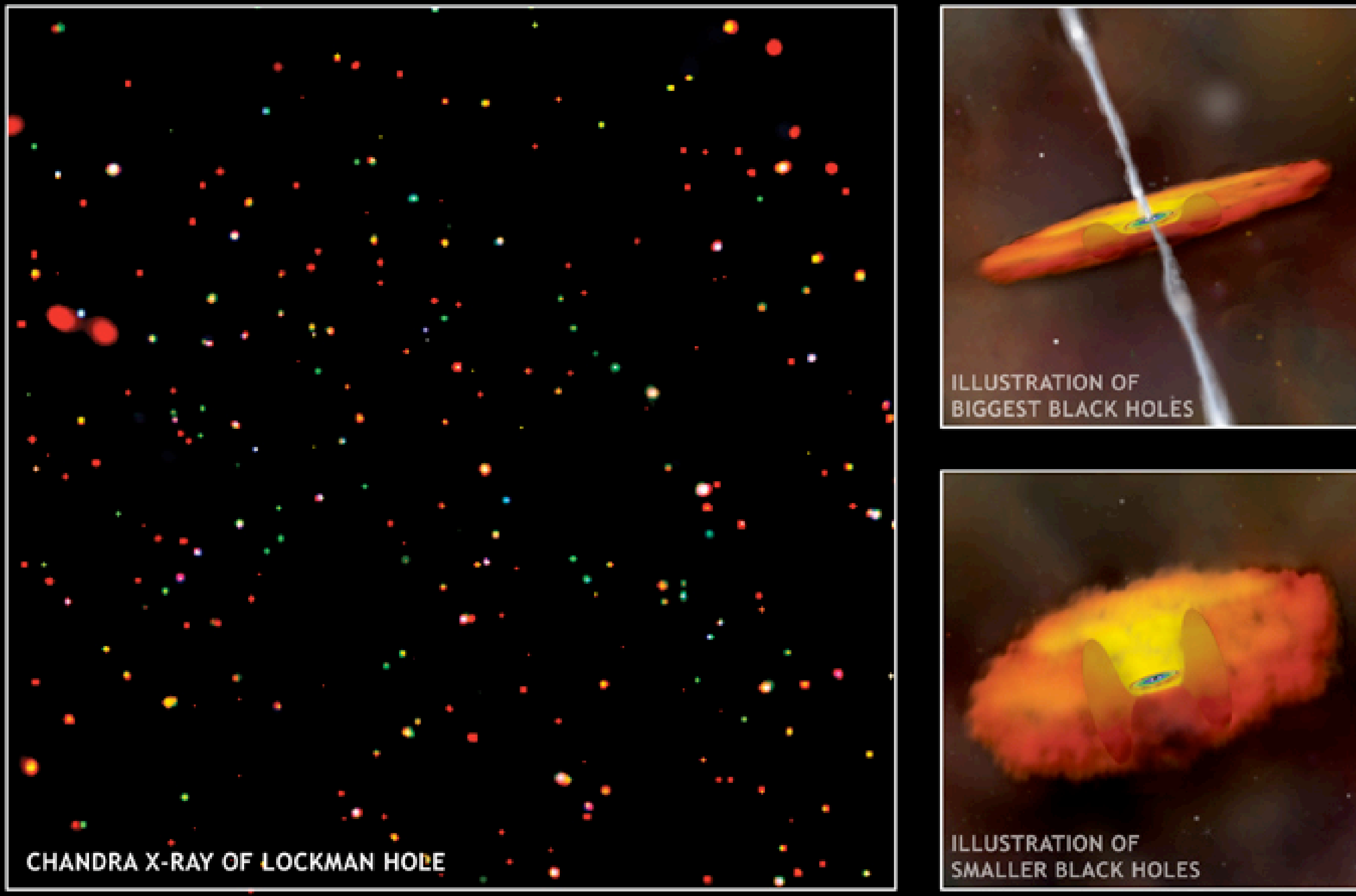
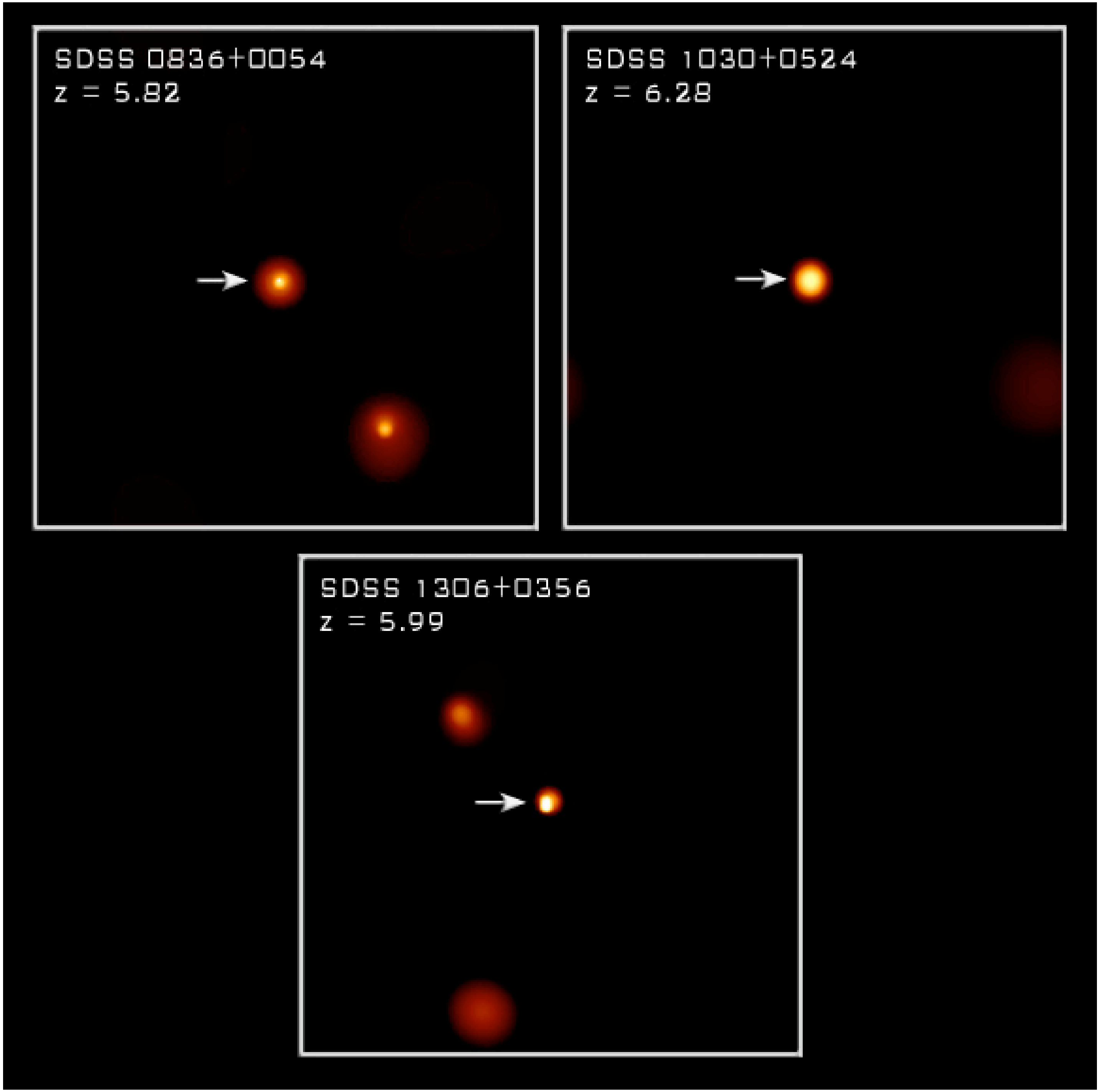


Growing Supermassive BH by z~6 with Quasistars

Elena M. Rossi

JILA, University of Colorado


CHANDRA X-RAY OF LOCKMAN HOLE
ILLUSTRATION OF
BIGGEST BLACK HOLES
ILLUSTRATION OF
SMALLER BLACK HOLES


SDSS 0836+0054
z = 5.82
SDSS 1030+0524
z = 6.28
SDSS 1306+0356
z = 5.99

NEED TO EXPLAIN:

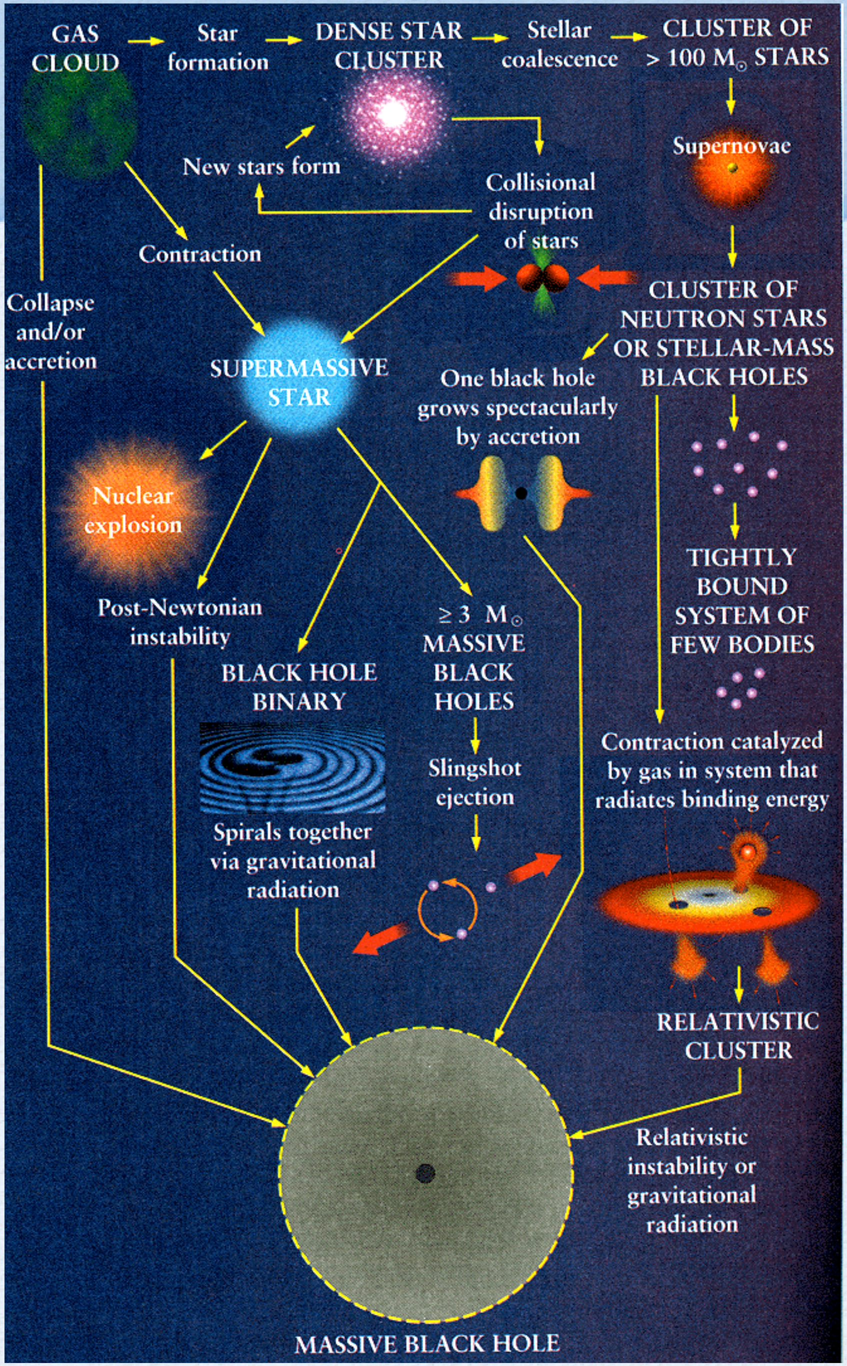
- **Ubiquity of BHs in present-day galaxies**
- **QSOs with $M > 10^9 M_\odot$ at $z > 6$**
  - **Age of Universe < 20 $t_{Salpeter}$** (for $\varepsilon \sim 0.1$)

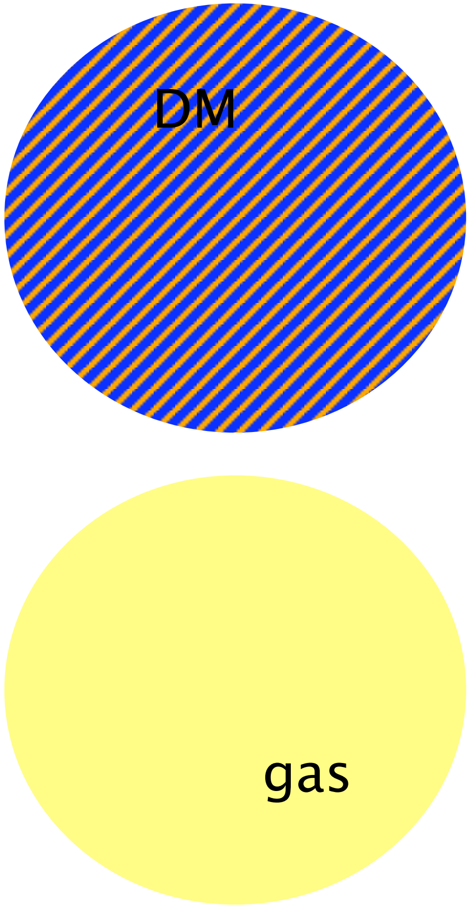
⇩

Eddington-limited accretion would have to:

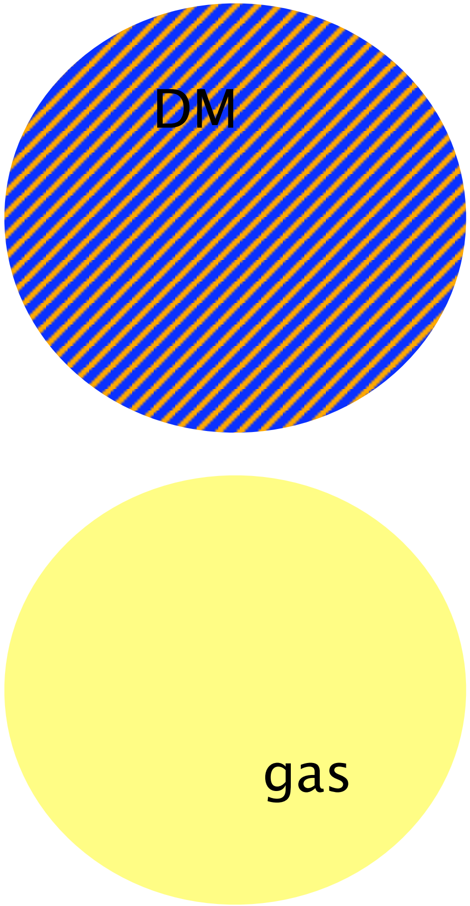
- **Start early** $z > 10$
- **Be nearly continuous**
- **Start with $M_{BH} > 10 - 100\ M_\odot$**

Begelman & Rees,
"Gravity's Fatal Attraction" 1996

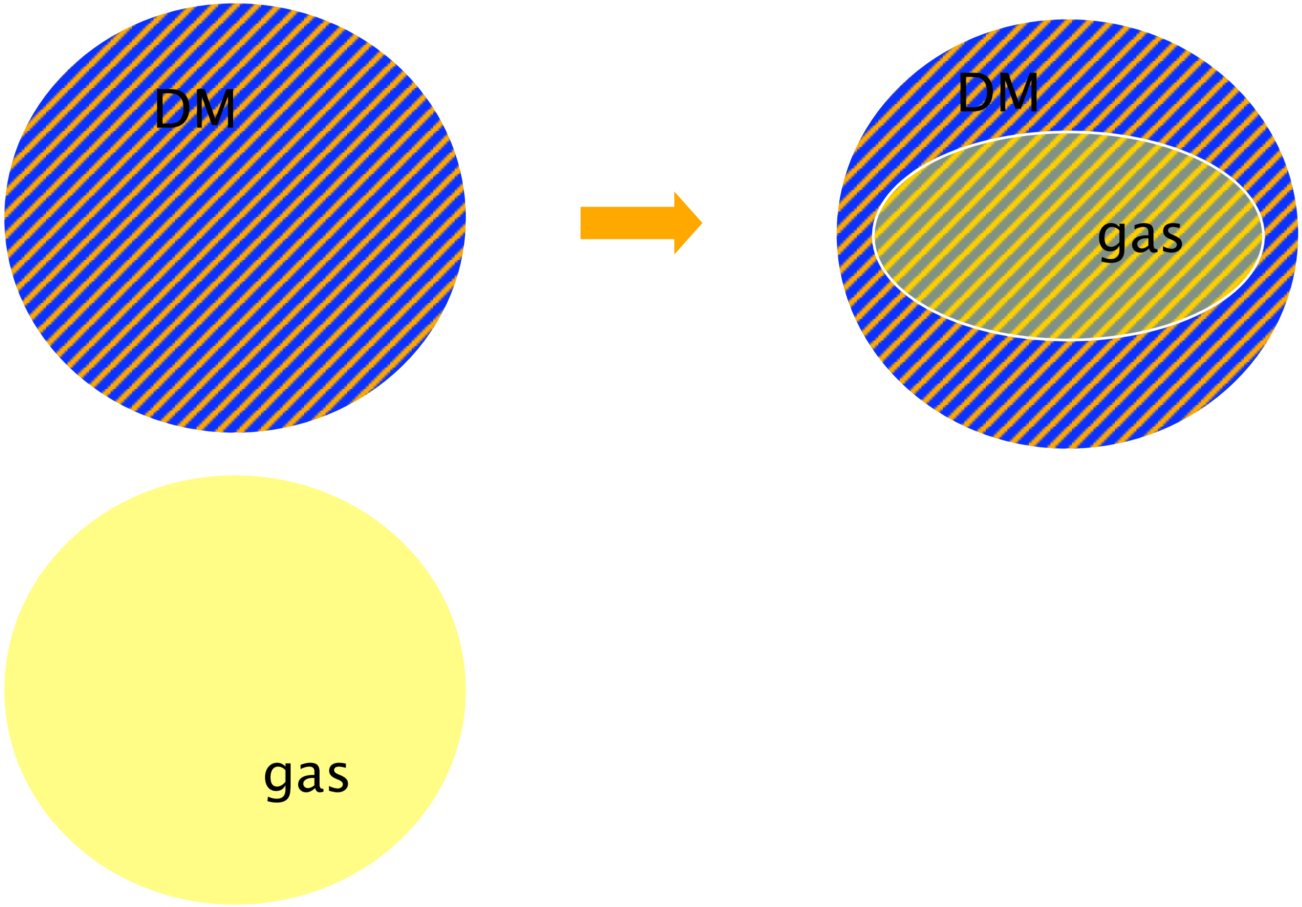


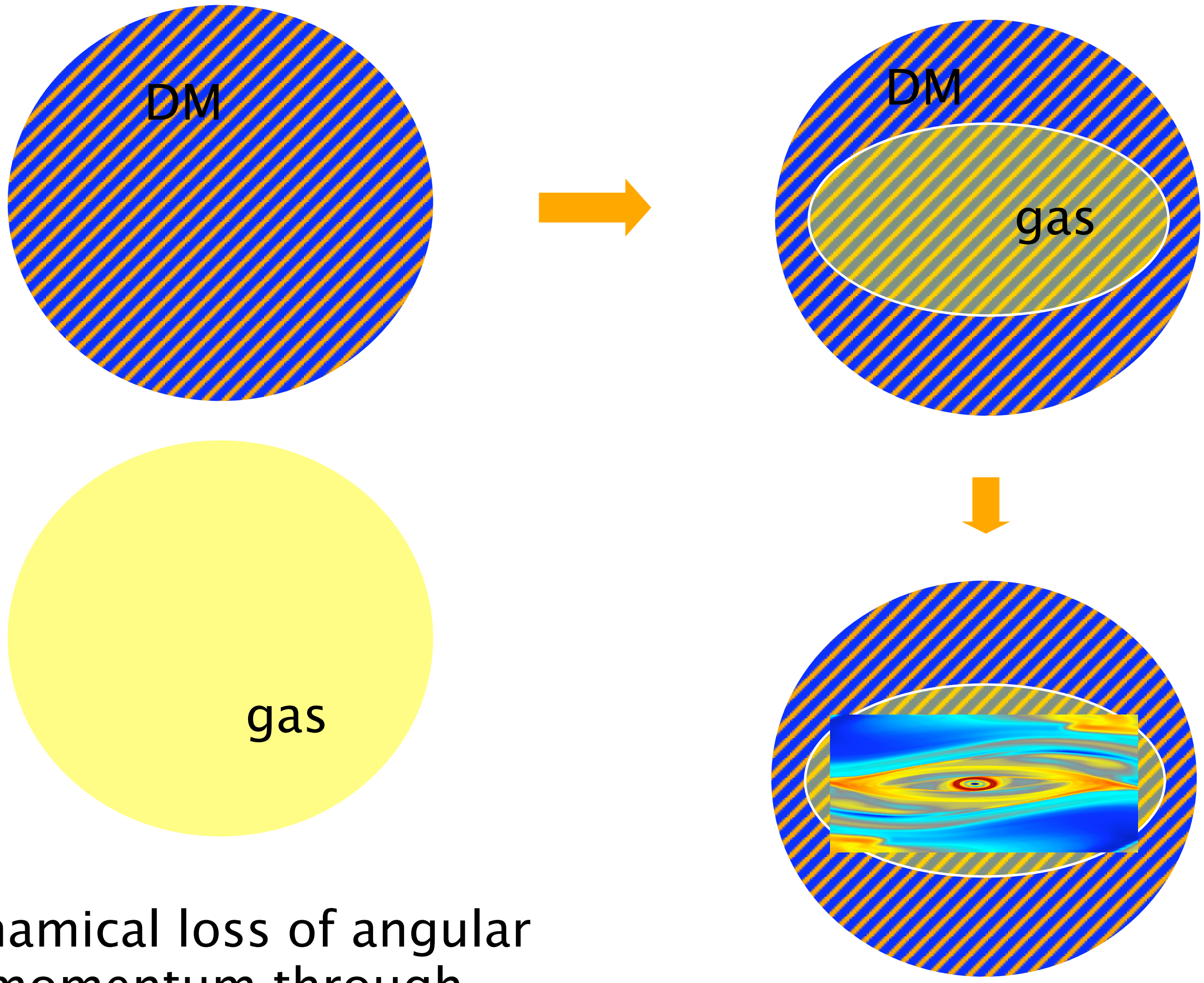

DM
gas

Halo with slight rotation



Gas collapses if $T_{gas} \leq T_{virial}$

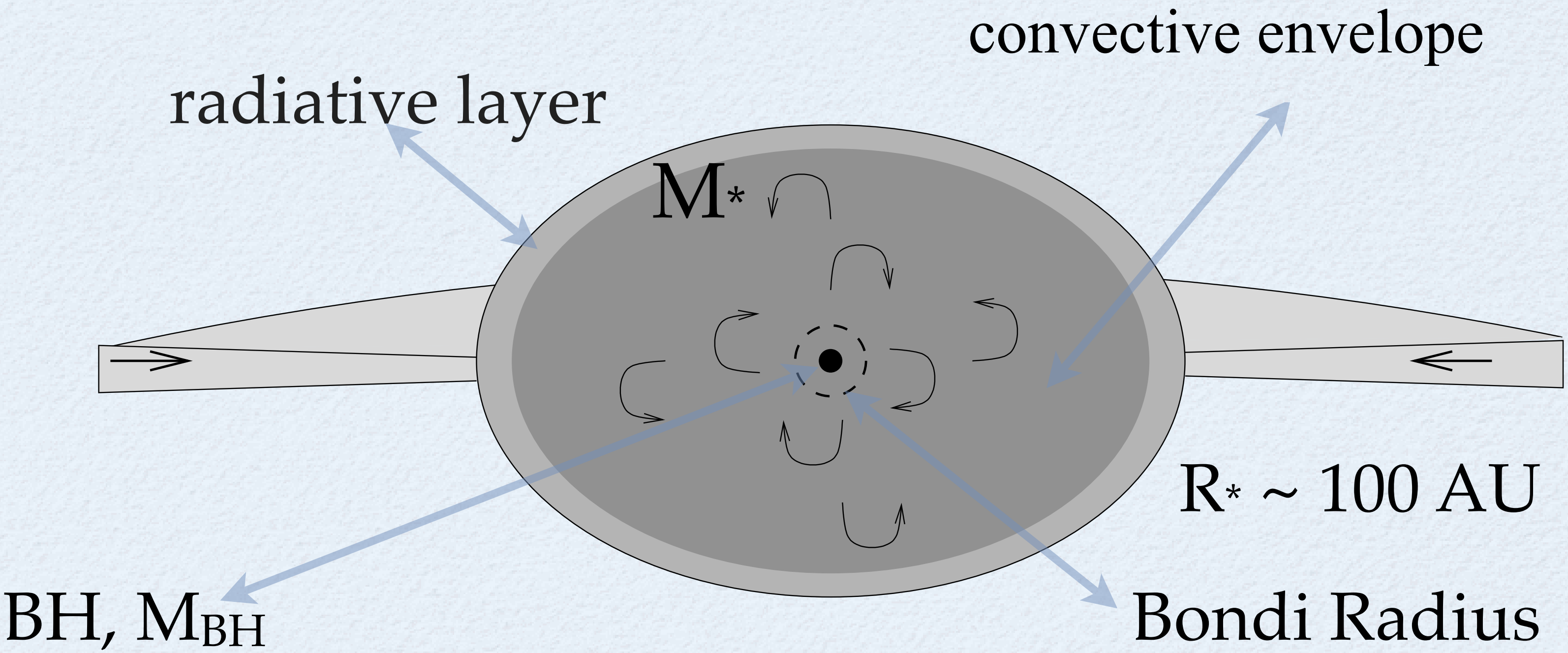




Dynamical loss of angular momentum through gravitational instabilities

Quasistar after BH forms

Begelman, Rossi & Armitage 07



looking for stable configurations for any M_{BH}

M_* and T_{ph}, to trace the evolution track for QS

Source of Energy

- **BH accretes adiabatically from Quasistar interior**

$$\dot{M}_{BH} \sim \dot{M}_{Bondi} \left(\frac{c_s}{c}\right)^2 \epsilon^{-1}$$

- **The luminosity depend on** ρ_c, T_c

$$L_{BH} = \alpha\epsilon\dot{M}_{BH}c^2 = \alpha\frac{4\pi}{\sqrt(2)}G^2 M_{BH}^2 \rho_c^{3/2} P_c^{-1/2}$$

energy sinks: jets, wind, inefficient convection etc.

Numerical Model

$$\frac{dP}{dr} = -\frac{GM(r)}{r^2}\rho$$

$$P = P_g + P_r$$

$$\frac{dM}{dr} = 4\pi r^2 \rho$$

$$\frac{L_{BH}}{4\pi r^2} = F_{con} + F_{rad}$$

Schwarzschild criterion for convective stability:

$$\frac{dT_{\rm rad}}{dr} - \frac{dT_{\rm ad}}{dr} > 0$$

+ numerical PoP III opacity from Mayer & Duschl 05

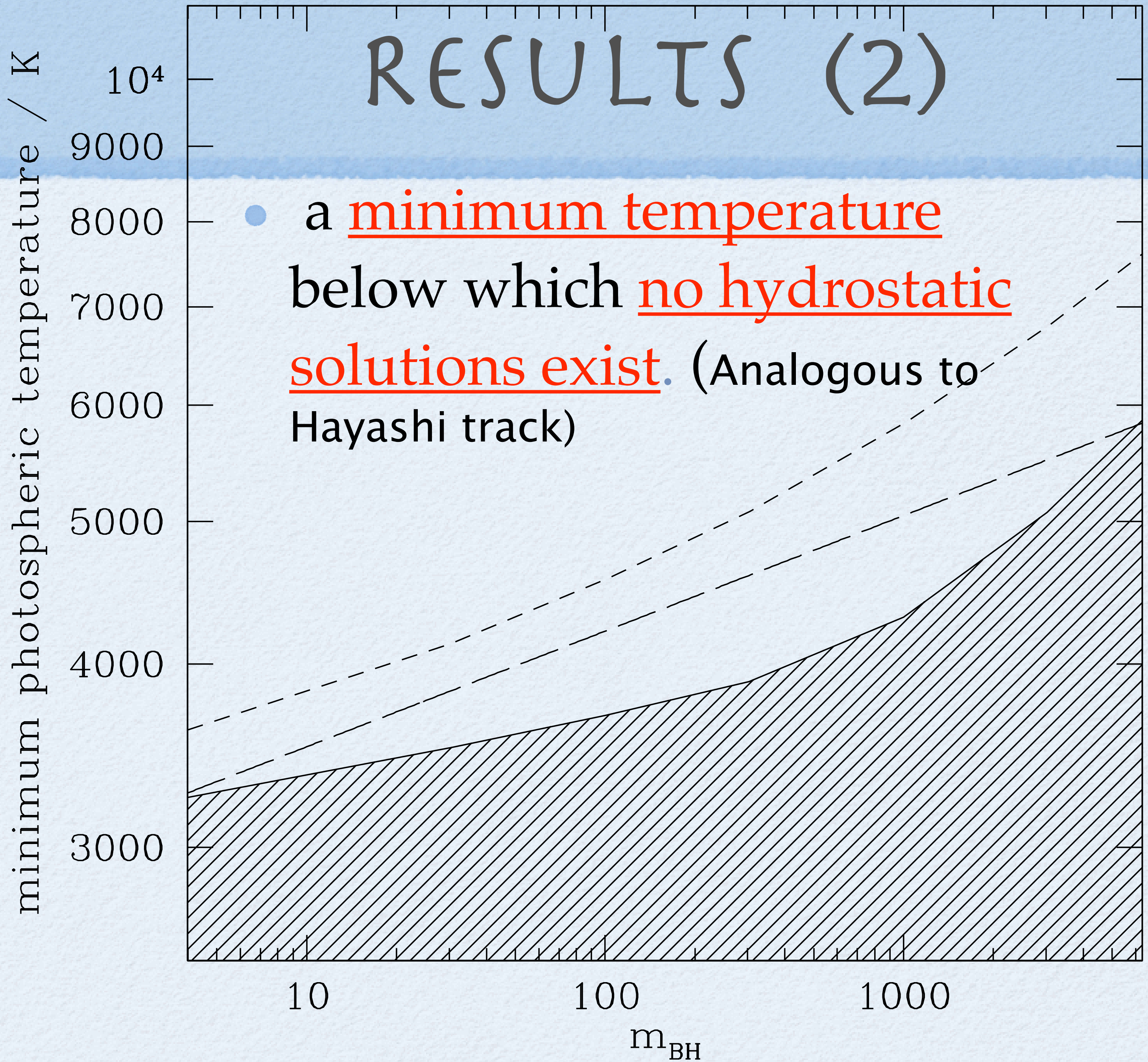
RESULT (1)

- The Black hole accretes at the the Eddington rate for the total mass (BH mass + envelope mass)
- since envelope mass is 100 times BH mass

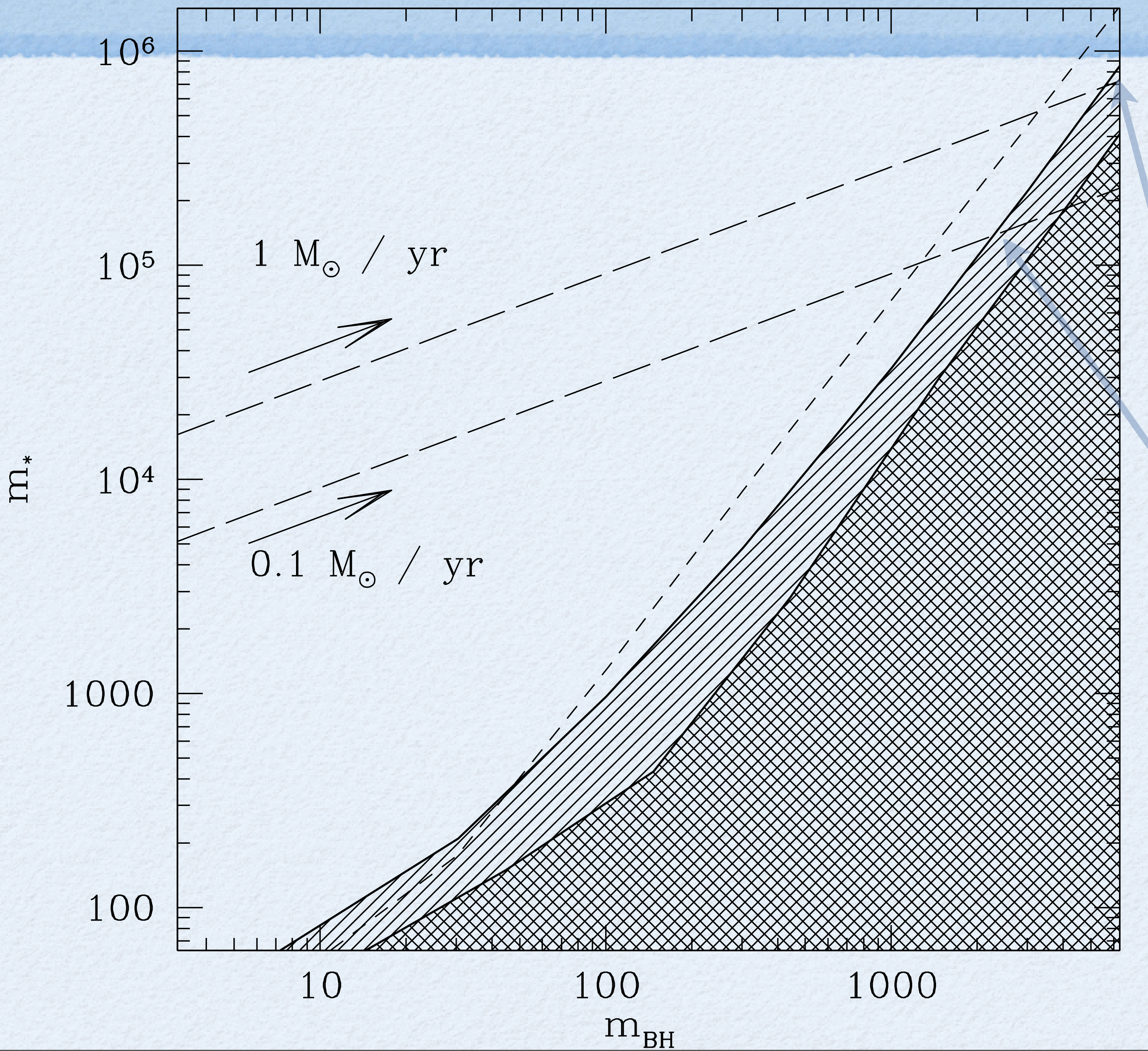
⇒ The BH accretes Super-Eddington !

Results (2)

- a <u>minimum temperature</u> below which <u>no hydrostatic solutions exist</u>. (Analogous to Hayashi track)



Result (3)



in ~ Myr
a BH with mass
10^3-10^4 M_{sun} !

Conclusions

1. BH seeds may grow super-Eddington inside a "quasistar"

2. Min. T_{eff} of ``QS" is ~ 4000 K, lifetime is > 10^6 yr

3. An intermidate-mass black hole is revealed when the QS evaporates

back up slides

DETECTING A QUASISTAR

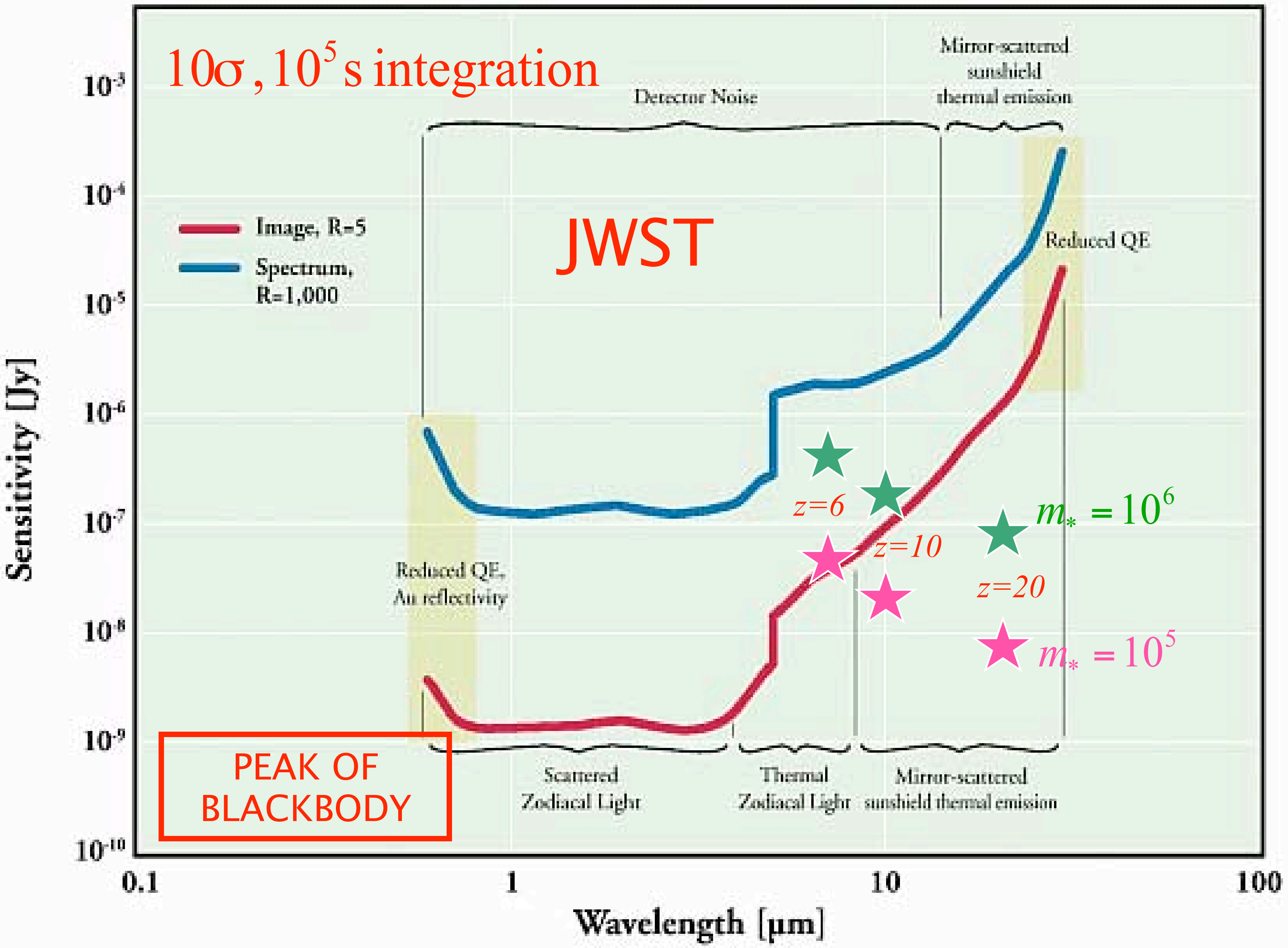
- **Most time spent as ~5000 K blackbody**
- **Radiates at Edddington limit for $10^5 m_5\ M_\odot$**

$$F_{\nu,\max} \sim 2.3\times10^{-5} m_5 T_{5000}^{-1}(1+z)D_{L,Gpc}^{-2}\ \mathrm{Jy}$$

$$\lambda_{\max} = (1+z)T_{5000}\ \mu m$$

- **Max flux ~**

$10^{-8} - 5\times10^{-7}$ Jy for $z \sim 6-20,\ m_* \sim 10^5 - 10^6$



10σ, 10^5 s integration
JWST
Detector Noise
Mirror-scattered sunshield thermal emission
Image, R=5
Spectrum, R=1,000
Reduced QE
Reduced QE, Au reflectivity
z=6
z=10
z=20
m* = 10^6
m* = 10^5
PEAK OF BLACKBODY
Scattered Zodiacal Light
Thermal Zodiacal Light
Mirror-scattered sunshield thermal emission
Sensitivity [Jy]
Wavelength [μm]
0.1
1
10
100
10^-3
10^-4
10^-5
10^-6
10^-7
10^-8
10^-9
10^-10

QUASISTAR STRUCTURE : PRE-BH

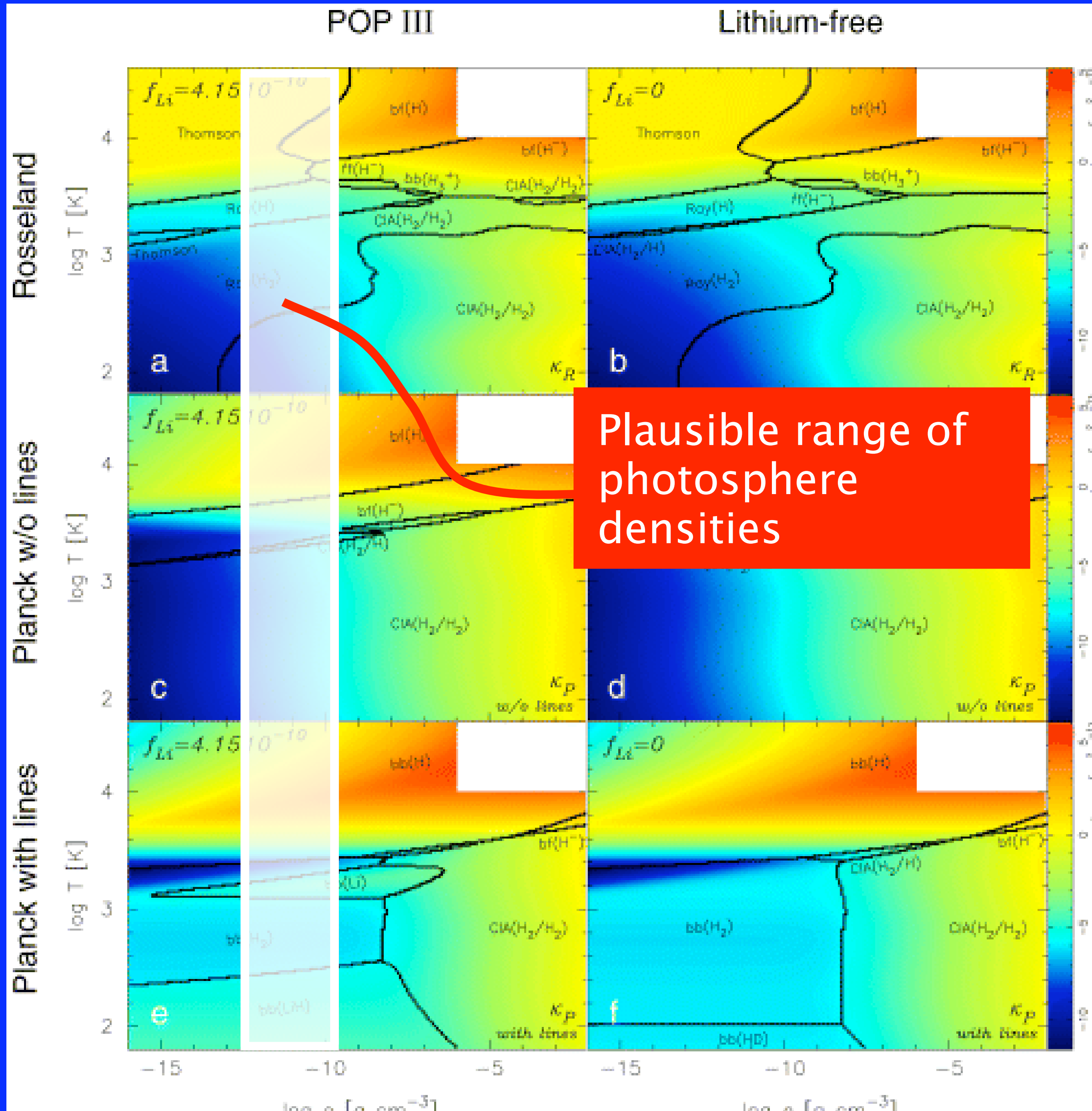
- **Mass m_* ($M_\odot$) increases with time** $0.1\,\dot{m}_{-1}$ $M_\odot$ yr^{-1}
- **Core with** $p_{gas} \sim p_{rad}$
- **Envelope** $p_{rad} / p_{gas} \propto r^{1/2} >> 1$
  - **Entropy increases outward – convectively stable**
  - **Rotation increases binding energy**
- **Outer radius** $r_* \sim 0.5\,\dot{m}_{-1}$ AU **constant**
- **Core radius** $r_c \sim r_* / m_*$ **shrinks**
  - **Nuclear burning inadequate to unbind star**
- **When core T** $\sim 5\times10^8$ K

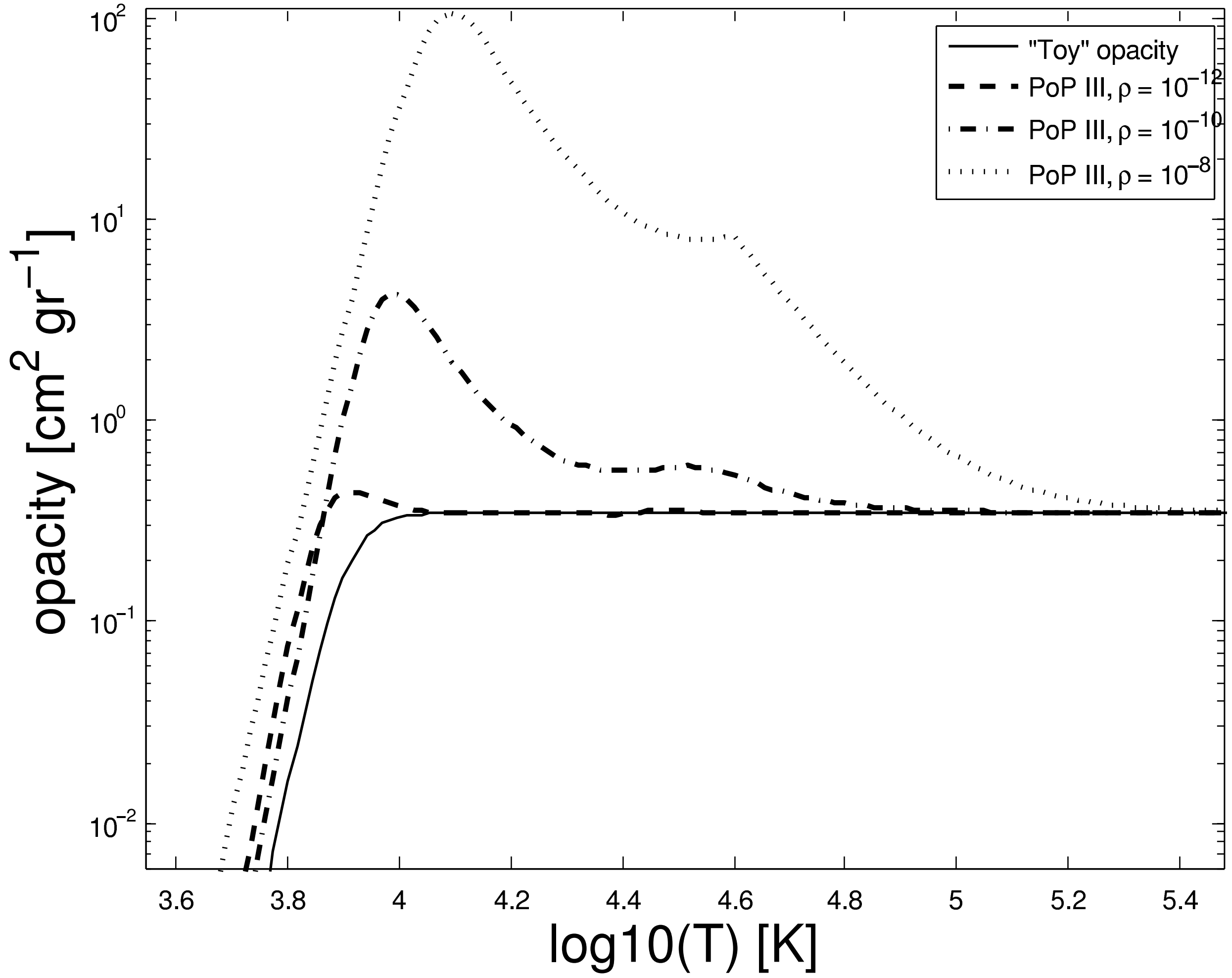
→ **rapid cooling by thermal neutrino**

Mayer & Duschl 2005

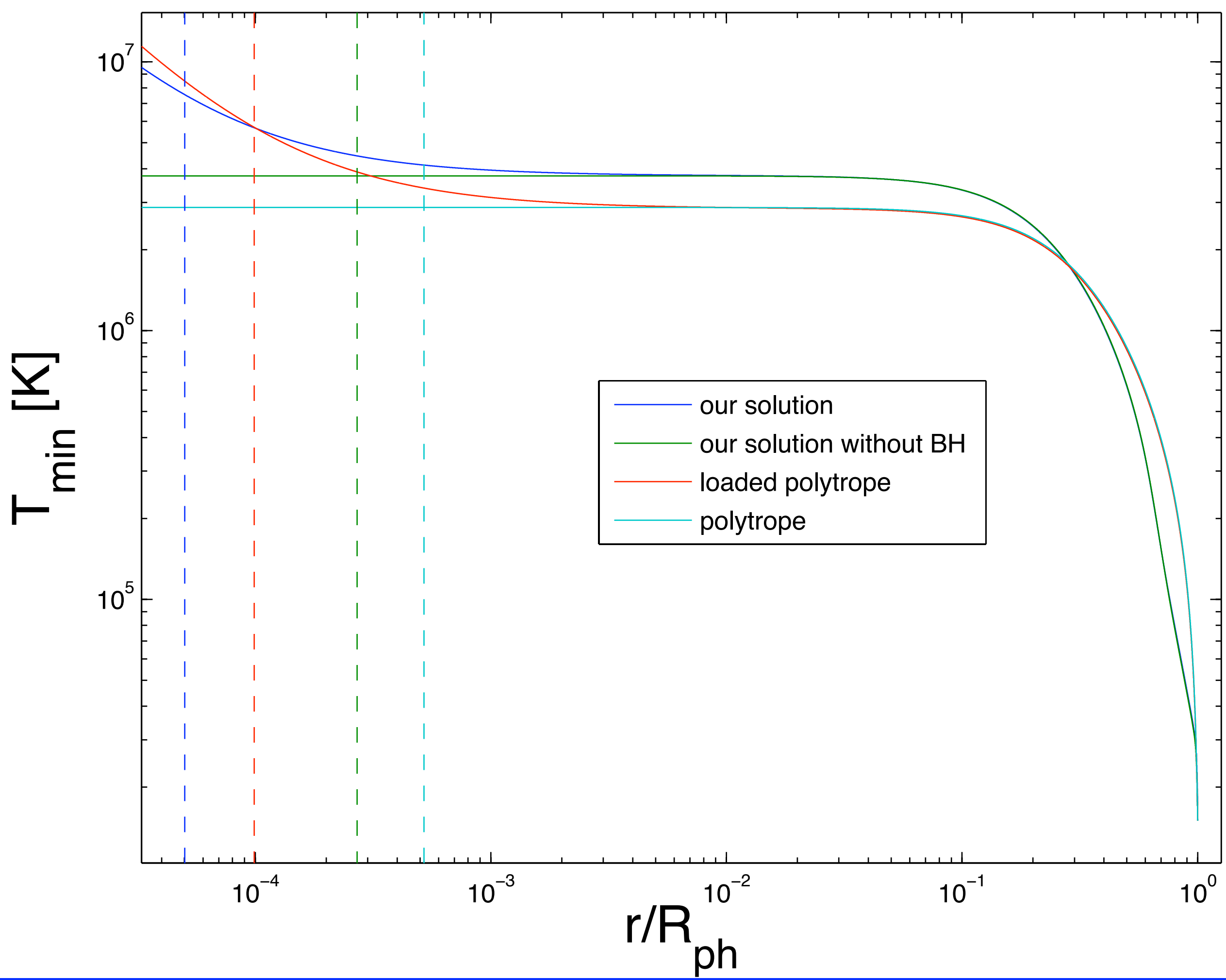
Metal-free opacities

Analogous to Hayashi track, but match to radiation-dominated convective envelope

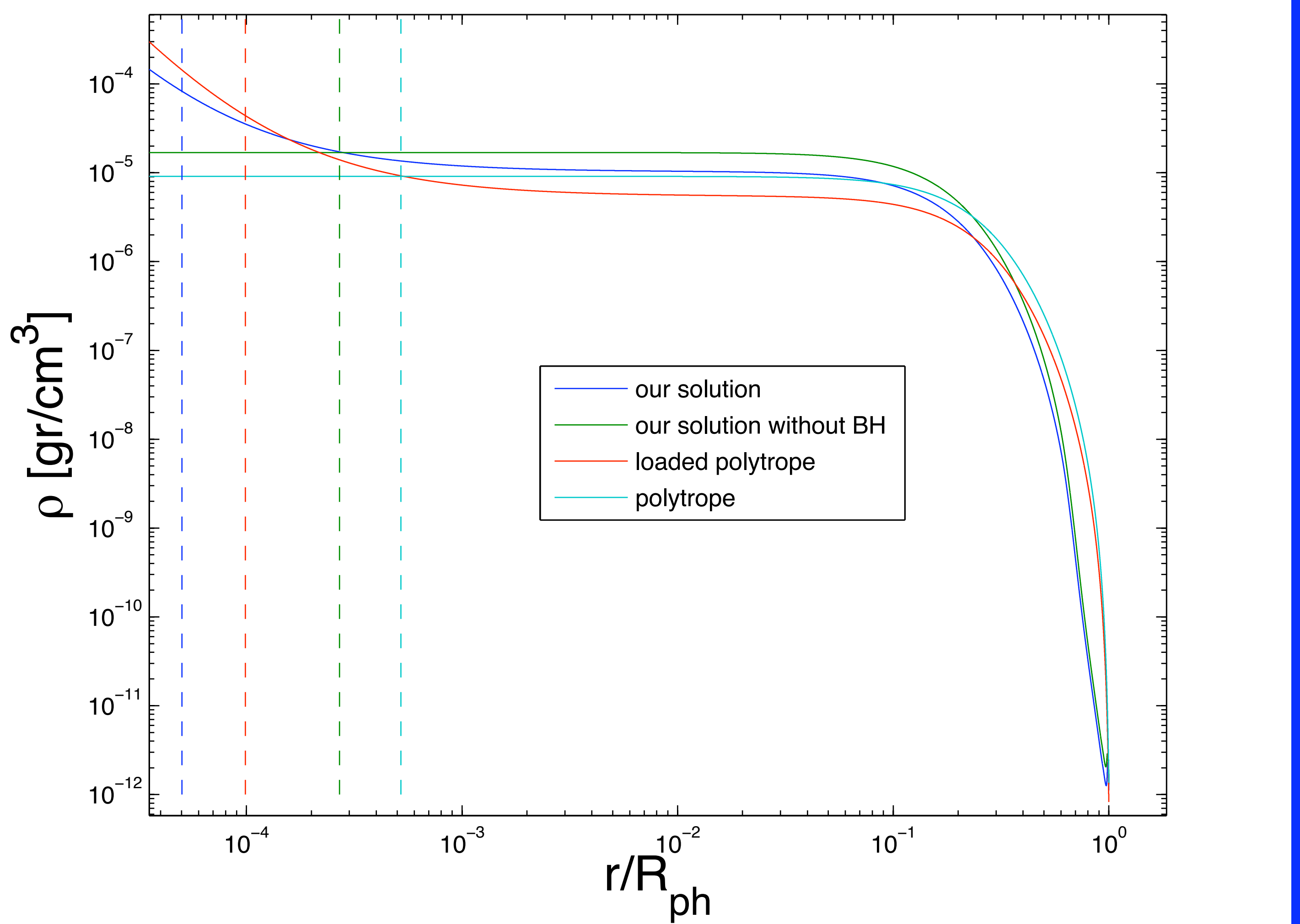




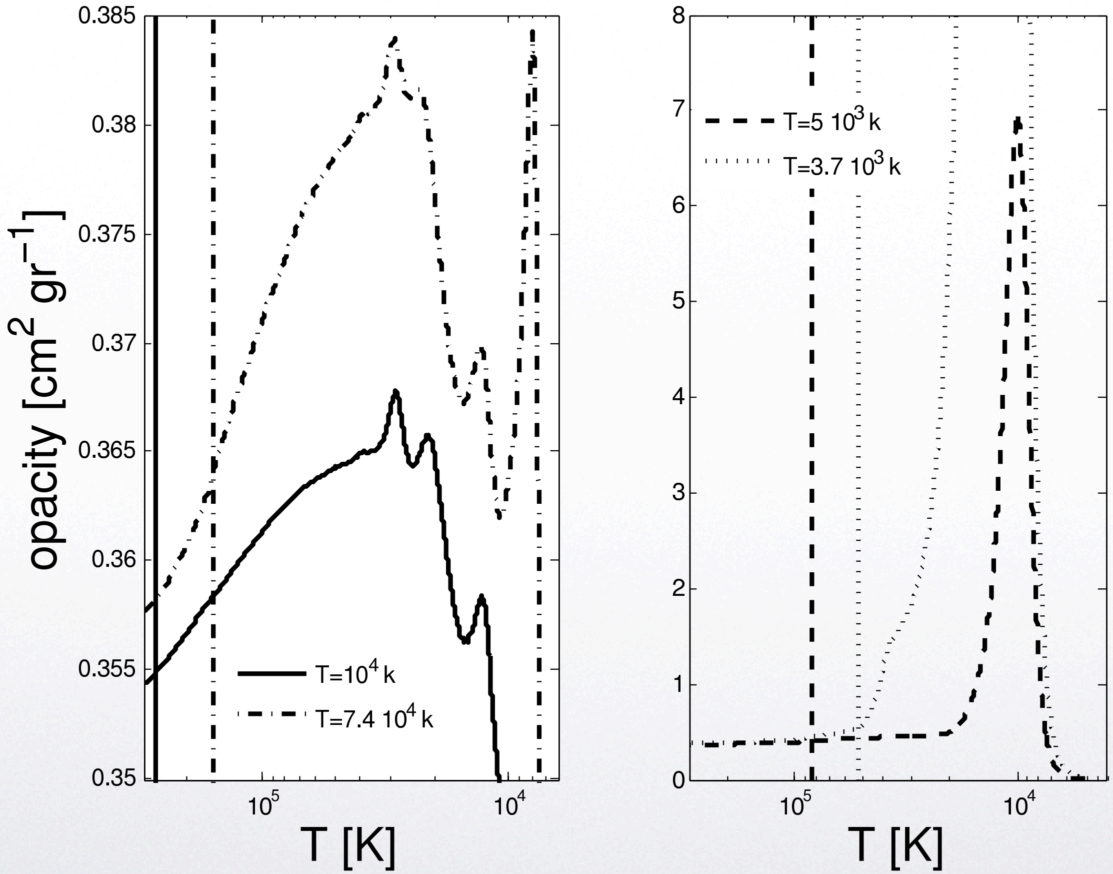
"Toy" opacity
PoP III, ρ = 10^−12
PoP III, ρ = 10^−10
PoP III, ρ = 10^−8
opacity [cm^2 gr^−1]
10^2
10^1
10^0
10^−1
10^−2
3.6
3.8
4
4.2
4.4
4.6
4.8
5
5.2
5.4
log10(T) [K]



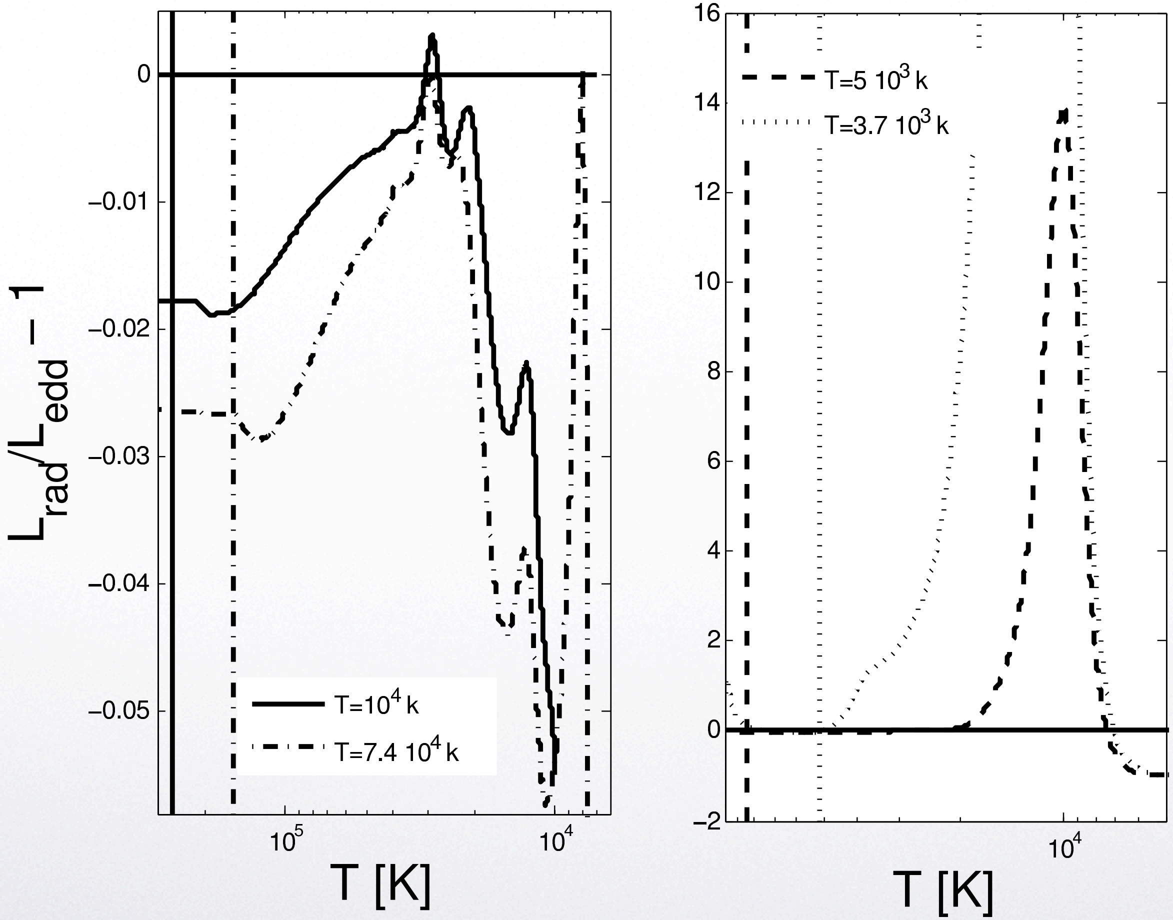
10^7
10^6
10^5
T_{min} [K]
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^0
r/R_{ph}
our solution
our solution without BH
loaded polytrope
polytrope

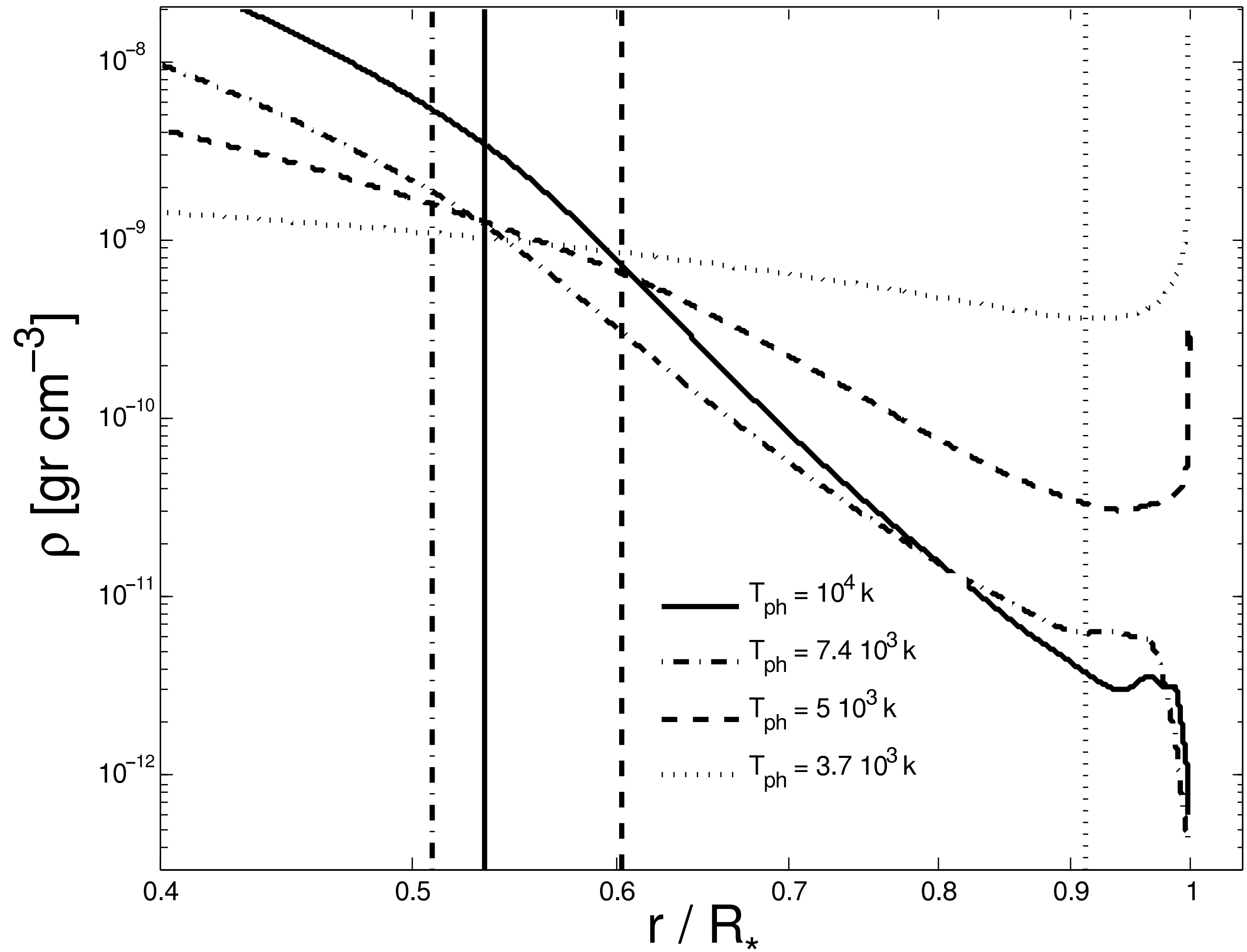

ρ [gr/cm^3]
r/R_ph
our solution
our solution without BH
loaded polytrope
polytrope
10^-4
10^-5
10^-6
10^-7
10^-8
10^-9
10^-10
10^-11
10^-12
10^-4
10^-3
10^-2
10^-1
10^0

Opacity behaviour in the radiative layer

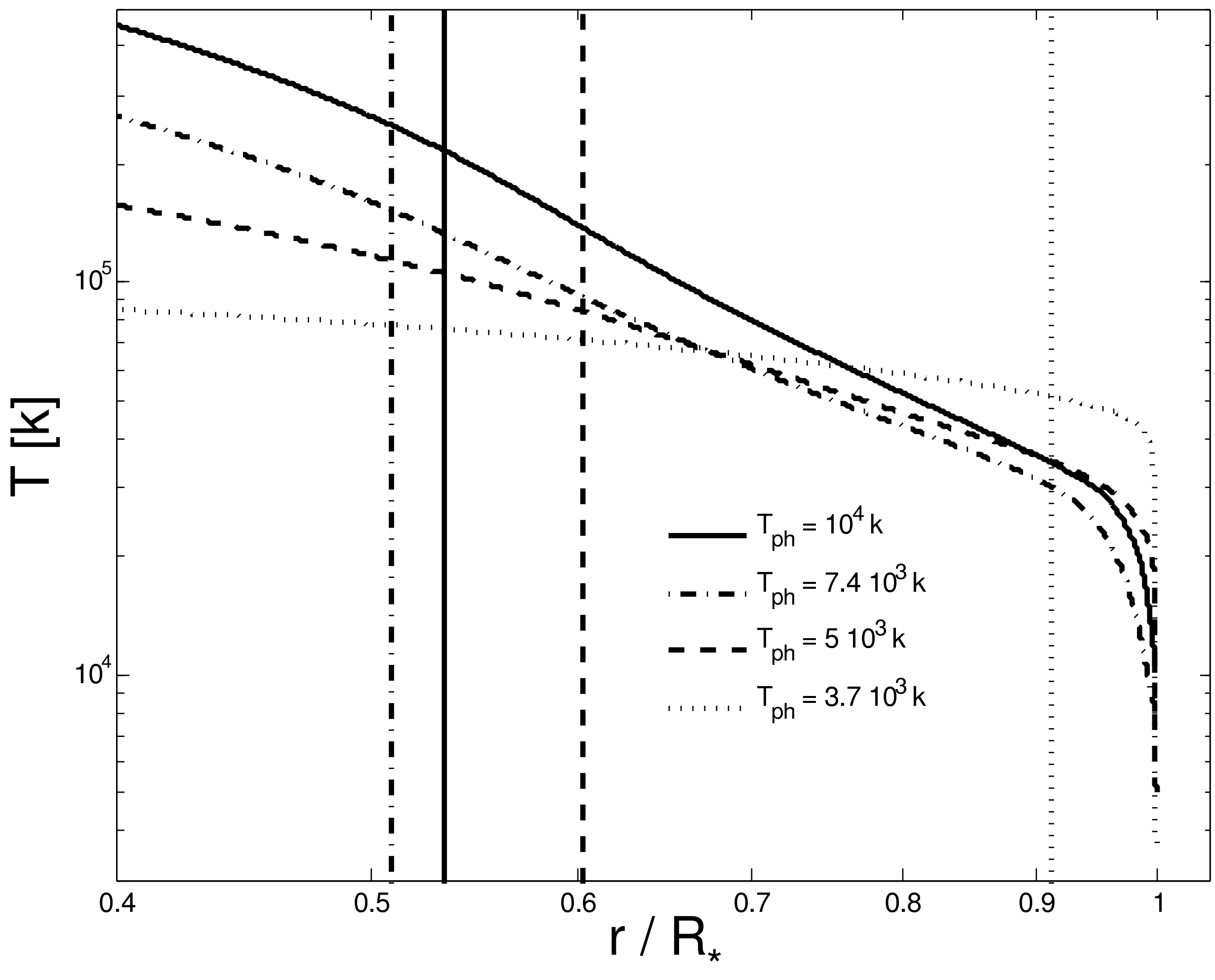


Eddigton ratio in the radiative layer





10^{-8}
10^{-9}
10^{-10}
10^{-11}
10^{-12}
0.4
0.5
0.6
0.7
0.8
0.9
1
ρ [gr cm^{-3}]
r / R_*
T_{ph} = 10^4 k
T_{ph} = 7.4 10^3 k
T_{ph} = 5 10^3 k
T_{ph} = 3.7 10^3 k



T [k]
10^5
10^4
0.4
0.5
0.6
0.7
0.8
0.9
1
r / R*
T_ph = 10^4 k
T_ph = 7.4 10^3 k
T_ph = 5 10^3 k
T_ph = 3.7 10^3 k

TEMP./METALLICITY DEPENDENCE

- $T_{halo} \sim 10^4$ K $\qquad M_{halo} \sim 10^9 M_{Solar}$
  - **Metal-free, H_2-dissociated gas falls in**
    - **(Metal rich and/or H_2 fragments?)**
  - **Inflow rate, mass accumulation** HIGH

FAVORS DIRECT BH FORMATION

- $T_{halo} \sim 10^2$ K $\qquad M_{halo} \sim 10^6 M_{Solar}$
  - **Infall requires H_2 or pollution by Pop III**
  - **Inflow rate, mass accumulation** LOW

FAVORS POP III STAR FORMATION